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## Dilepton Production from Dropping $\rho$ in the Vector Manifestation\*

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In this write-up we summarize the main result of our analysis on the thermal dilepton production rate from the dropping  $\rho$  based on the vector manifestation (VM). In the analysis, we showed that the effect of the strong violation of the vector dominance (VD) predicted by the VM, substantially suppresses the dilepton production rate compared with the one predicted by assuming the VD together with the dropping  $\rho$ .

*Keywords:* Dropping mass; Chiral Symmetry; Vector meson.

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Changes of hadron properties are indications of chiral symmetry restoration occurring in hot and/or dense QCD and have been explored using various effective chiral approaches<sup>2,3</sup>. An enhancement of dielectron mass spectra below the  $\rho/\omega$  resonance was first observed at CERN SPS<sup>4</sup>, which can be explained by the dropping masses of hadrons following the Brown-Rho (BR) scaling<sup>5</sup> (see e.g., Ref. 3).

The vector manifestation (VM)<sup>6</sup> is a novel pattern of the Wigner realization of chiral symmetry in which the  $\rho$  meson becomes massless degenerate with the pion at the chiral phase transition point. The VM is formulated<sup>7,8,9,10</sup> in the effective field theory based on the hidden local symmetry (HLS)<sup>11</sup>, and thus gives a field theoretical description of the dropping  $\rho$  mass.

The dropping mass is supported by the mass shift of the  $\omega$  meson in nuclei measured by the KEK-PS E325 Experiment<sup>12</sup> and the CBELSA/TAPS Collaboration<sup>13</sup>. Furthermore, recent Phenix data cannot be explained by a hadronic model<sup>14</sup>, which might indicate changes of some properties of vector mesons. It seems difficult to explain the dimuon data from NA60 by a naive dropping  $\rho$ <sup>15</sup>. However, the strong violation of the vector dominance (VD) is not considered, which is one of the significant predictions of the VM<sup>16</sup> and plays an important role<sup>17</sup>.

In Ref. 1, we studied the dilepton production rate from the dropping  $\rho$  based on the VM using the HLS theory at finite temperature. We paid a special attention

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to the effect of the violation of the vector dominance (indicated by “~~VD~~”) which is due to the *intrinsic temperature effects* of the parameters introduced through the matching to QCD in the Wilsonian sense. We made a comparison of the dilepton production rates predicted by the VM with the ones by the dropping  $\rho$  under the assumption of the VD. The result shows that the effect of the ~~VD~~ substantially suppresses the dilepton production rate compared with the one predicted by assuming the VD together with the dropping  $\rho$ .

The VM was formulated<sup>7,8,9,10</sup> in the effective field theory based on the HLS<sup>11</sup>. At the leading order the HLS Lagrangian includes three parameters: the pion decay constant  $F_\pi$ ; the HLS gauge coupling  $g$ ; and a parameter  $a$ . Using these three parameters, the  $\rho$  meson mass  $m_\rho$  and the direct  $\gamma$ - $\pi$ - $\pi$  coupling strength  $g_{\gamma\pi\pi}$  are expressed as  $m_\rho^2 = g^2 a F_\pi^2$  and  $g_{\gamma\pi\pi} = 1 - \frac{a}{2}$ . From these expressions, one can easily see that the VD of the electromagnetic form factor of the pion, i.e.  $g_{\gamma\pi\pi} = 0$ , is satisfied for  $a = 2$ .

The most important ingredient to formulate the VM in hot matter is the following intrinsic temperature dependences of the bare parameters  $a$  and  $g$ <sup>8,10</sup>:

$$g(\Lambda; T) \sim \langle \bar{q}q \rangle \rightarrow 0, \quad a(\Lambda; T) - 1 \sim \langle \bar{q}q \rangle^2 \rightarrow 0, \quad (1)$$

for  $T \rightarrow T_c$ . As a result, the vector meson pole mass also goes to zero for  $T \rightarrow T_c$ :

$$m_\rho(T) \sim \langle \bar{q}q \rangle \rightarrow 0. \quad (2)$$

We would like to stress that the VD is strongly violated near the critical point associated with the dropping  $\rho$  in the VM in hot matter<sup>16</sup>:

$$a(T) \rightarrow 1, \quad \text{for } T \rightarrow T_c. \quad (3)$$

We should note that the conditions in Eq. (1) hold *only in the vicinity of  $T_c$* : They are not valid any more far away from  $T_c$  where ordinary hadronic temperature corrections are dominant. For expressing a temperature above which the intrinsic effect becomes important, we introduce a temperature  $T_f$ , so-called flash temperature<sup>18</sup>. The VM and therefore the dropping  $\rho$  mass become transparent for  $T > T_f$ . On the other hand, we expect that the intrinsic effects are negligible in the low-temperature region below  $T_f$ : Only hadronic temperature corrections are considered for  $T < T_f$ . Based on the above consideration, we adopt the following ansatz of the temperature dependences of the bare  $g$  and  $a$ :

$$g(\Lambda; T) \propto \langle \bar{q}q \rangle_T, \quad a(\Lambda; T) - 1 \propto \langle \bar{q}q \rangle_T^2 \quad \text{for } T > T_f, \quad (4)$$

while  $g(\Lambda; T)$  and  $a(\Lambda; T)$  are constants for  $T < T_f$ .

As noted, the vector dominance (VD) is controlled by the parameter  $a$  in the HLS theory. The VM leads to the strong violation of the VD (indicated by “~~VD~~”) near the chiral symmetry restoration point, which can be traced through the Wilsonian matching and the RG evolutions. Thus the direct photon- $\pi$ - $\pi$  coupling  $g_{\gamma\pi\pi}$  yields non-vanishing contribution to the form factor together with the  $\rho$ -meson exchange. In Ref. 1, we compared the dilepton spectra predicted in the VM (including the effect

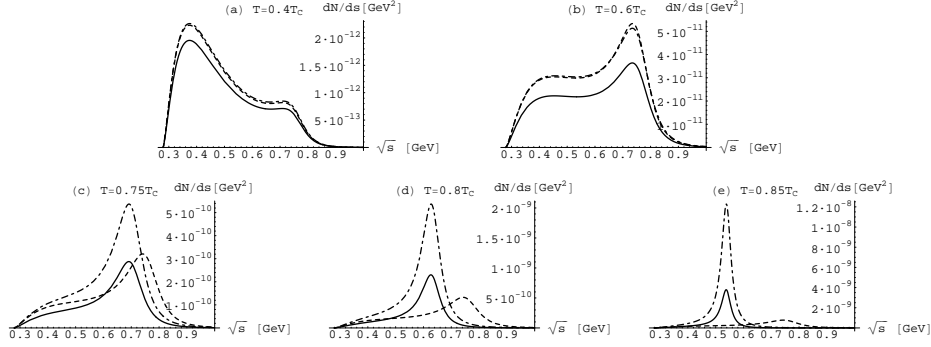
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Fig. 1. Dilepton production rate as a function of the invariant mass  $\sqrt{s}$  for various temperatures. The solid curves include the effects of the violation of the VD. The dashed-dotted curves correspond to the analysis assuming the VD. The dashed curves represent the result with the parameters at zero temperature.

of  $\mathcal{V}\mathcal{D}$ ) with those obtained by assuming the VD, i.e. taking  $g_{\gamma\pi\pi} = 0$ . Figure 1 shows the form factor and the dilepton production rate integrated over three-momentum, in which the results with VD and  $\mathcal{V}\mathcal{D}$  were compared. The figure shows a clear difference between the curves with VD and  $\mathcal{V}\mathcal{D}$ . It can be easily seen that the  $\mathcal{V}\mathcal{D}$  gives a reduction compared to the case with keeping the VD. The features of the dilepton production rate coming from two-pion annihilation shown in Fig. 1(a)-(e) are summarized below for each temperature:

**(a) and (b) (below  $T_f$ ) :** In both (a) and (b), the dilepton rates for  $\mathcal{V}\mathcal{D}$  (indicated by solid curves) are suppressed compared with those for VD (indicated by dashed-dotted curves). This is due to decreasing of the  $\rho$ - $\gamma$  mixing strength  $g_\rho$  at finite temperature for  $\mathcal{V}\mathcal{D}$ . In case with VD, however,  $g_\rho$  is almost constant, and the dashed-dotted curves almost coincide with the dashed ones for the vacuum  $\rho$ .

**(c), (d) and (e) (above  $T_f$ ) :** A shift of the  $\rho$  meson mass to lower-mass region can be seen. Furthermore, the production rate based on the VM (i.e., the case with  $\mathcal{V}\mathcal{D}$ ) is suppressed compared to that with the VD. We observe that the suppression is more transparent for larger temperature: The suppression factor is  $\sim 1.8$  in (c),  $\sim 2$  in (d) and  $\sim 3.3$  in (e).

As one can see in (c), the peak value of the rate predicted by the VM for  $T \gtrsim T_f$  is even smaller than the one obtained by the vacuum parameters, and the shapes of them are quite similar to each other. This indicates that it might be difficult to measure the signal of the dropping  $\rho$  experimentally, if this temperature region is dominant in the evolution. In the case shown in (d), on the other hand, the rate by the VM is enhanced by a factor of about two compared with the one by the vacuum  $\rho$ . The enhancement becomes prominent near the critical temperature as seen in (e). These imply that we may have a chance to discriminate the dropping  $\rho$  from the vacuum  $\rho$ .

We cannot make a direct comparison of our results with experimental data. However a *naïve* dropping  $m_\rho$  formula, i.e.,  $T_f = 0$ , as well as VD in hot/dense matter are sometimes used for theoretical implications of the data. As we have shown, the violation of the VD gives a clear difference from the results without including the effect. It may be then expected that a field theoretical analysis of the dropping  $\rho$  as presented in this work and a reliable comparison with dilepton measurements will provide an evidence for the in-medium hadronic properties associated with the chiral symmetry restoration, if complicated hadronization processes do not wash out those changes.

Recently the chiral perturbation theory with including vector and axial-vector mesons as well as pions has been constructed<sup>19</sup>. It is interesting to see the effect of inclusion of the axial-vector meson to the dilepton rate<sup>20</sup>.

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